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ONGOING CASE STUDIES PRESENTED AT THE ARMY SYMPOSIUM ON SOLID M--ETC(U)

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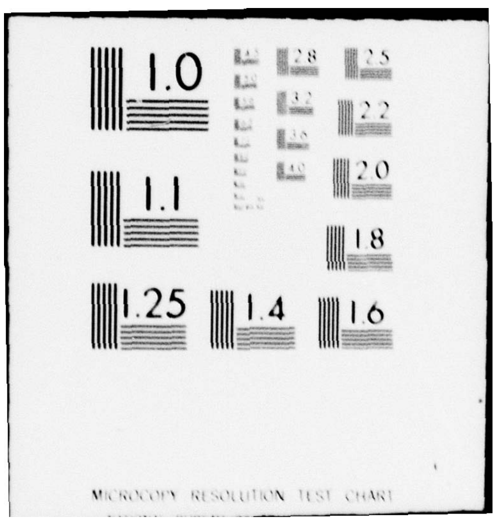
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ONGOING CASE STUDIES PRESENTED AT THE ARMY SYMPOSIUM ON SOLID MECHANICS, 1978 - CASE STUDIES ON STRUCTURAL INTEGRITY AND RELIABILITY,

held at Bass River, Cape Cod,
Massachusetts, 3-5 October 1978.

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This report discusses the Ongoing Case Studies presented at the Army Symposium on Solid Mechanics, 1978-Case Studies on Structural Integrity and Reliability, held at Bass River (Cape Cod), Massachusetts, 3-5 October 1978.

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Detectors
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Embrittlement
Environments
Epoxy Resins
Failure
Fatigue (mechanics)
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High Temperature
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Life (durability)
Loads (forces)
Maintenance
Materials
Mechanics
Nondestructive Testing
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Pins
Predictions
Pressure Vessels
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Strain Gages
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Stress Corrosion
Stresses
Structural Properties
Structural Response
Structures
Theorems
Toughness
Vehicular Tracks
Vibration
Vulnerability
Wings

PREFACE

This document contains abstracts of ongoing case studies which were acceptable for presentation within the Ongoing Case Studies Session at the Army Symposium on Solid Mechanics, 1978. Unfortunately, not all of the papers could be scheduled for oral presentation at the symposium due to time limitations. Those which were not presented orally are so identified on page vi of the table of contents. This session was comprised of a series of brief presentations and discussions of current (but not necessarily complete case studies relating to the theme of the conference: "Case Studies on Structural Integrity and Reliability." This meeting was held at Bass River (Cape Cod), Massachusetts on 3-5 October 1978. The proceedings of this symposium are published in a companion document: Army Materials and Mechanics Research Center, Monograph Series Report, AMMRC MS 78-3, dated September 1978.

We acknowledge the contributions of the authors cited in the table of contents and also the clerical staff of the Mechanics Research Laboratory and the Technical Reports Office of the Army Materials and Mechanics Research Center for their unflagging efforts in the preparation and printing of this document, the proceedings and numerous other symposium materials.

PREVIOUS DOCUMENTS IN THIS SYMPOSIA SERIES*

Proceedings of the Army Symposium on Solid Mechanics, 1968,
AMMRC MS 68-09, September 1968, AD 675 463

Proceedings of the Army Symposium on Solid Mechanics, 1970 -
Lightweight Structures,
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Proceedings of the Army Symposium on Solid Mechanics, 1972 -
The Role of Mechanics in Design - Ballistic Problems,
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Proceedings of the Army Symposium on Solid Mechanics, 1974:
The Role of Mechanics in Design - Structural Joints,
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Stress Analysis of Structural Joints and Interfaces -
A Selective Annotated Bibliography
by M. M. Murphy and E. M. Lenoe,
AMMRC MS 74-10, September 1974, AD 786 520

Proceedings of the Army Symposium on Solid Mechanics, 1976 -
Composite Materials: The Influence of Mechanics of Failure on Design,
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Work-In-Progress Presented at the Army Symposium on Solid Mechanics, 1976 -
Composite Materials: The Influence of Mechanics of Failure on Design,
AMMRC MS 76-3, September 1976, AD A029 736

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* These documents may be ordered from the National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22161

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Army Construction Engineering Research Laboratory

ONGOING CASE STUDIES SESSION

G. E. MADDUX, Co-Chairman, Air Force Flight Dynamics Laboratory
R. P. PAPIRNO, Co-Chairman, AMMRC

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*Not presented orally due to time limitations.

SESSION IV: ONGOING CASE STUDIES

Co-Chairmen

G. E. MADDUX
Aerospace Engineer
Air Force Flight Dynamics Laboratory

and

R. P. PAPIRNO
Research Mechanical Engineer
Army Materials and Mechanics Research Center

IMPLICATION OF HIGH TEMPERATURE SLOW CRACK GROWTH ON CERAMIC MISSILE RADOME DESIGN

E. Lenoe, G. Driscoll, J. Peters, D. Neal and C. Freese
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

ABSTRACT

This paper will summerize AMMRC's recent developments in high temperature (up to 2200°F) characterization of slip cast fused silica (SCFS) for strength and slow crack growth behavior of specimens removed from high and low stressed radomes.

Probability of survival (P_s) estimates are based upon empirical time to failure tests in conjunction with statistical mechanics analysis for a typical radome using flight profile data (mechanical and thermal loading). Implication of time dependent behavior at elevated temperatures are explored with regards to radome life. The particular model is a SCFS ceramic radome with fiber glass and epoxy adapter ring bonded by an AF-32 adhesive. P_s estimates for specific structural elements, bonding agent, fiber glass and graphite epoxy, are determined from stress-strength Warner Diagram calculators. P_s values for individual structural elements of SCFS were obtained from the Weibull statistics representing the effects of volume, stress and material strength. P_s results for the entire structure are obtained by multiplying together all elements P_s values in the structure. The multiplication procedure introduces survival independence between elements of radome, thereby, describing a more conservative estimate.

In determining the stress distribution, a finite element code was developed for both mechanical and thermal loads for radome applications. The code utilizes an 8 noded isoparametric element with substructuring capabilities. Each element contains 16 degrees of freedom with the entire model containing 2700 degrees of freedom. AMMRC's development of high temperature characterizations of SCFS combined with a new finite element code for radome applications has provided the necessary means for adequate reliability determinations of missile radomes.

A strength-probability-time (SPT) diagram is introduced for SCFS high temperature data, providing an aid to the design engineers using SCFS in missile radomes. For given conditions of stress state and distribution, environment, temperature and component size, the diagram enables estimates of a safe working stress to be made for specific component lifetime and survival probabilities.

ASSESSMENT OF THE STRUCTURAL INTEGRITY OF THE T-39A AIRCRAFT WING

A. G. Denyer and J. H. Stolpestad
Rockwell International, Los Angeles Division
Los Angeles, California 90009

ABSTRACT

The U.S. Air Force has plans to use the T-39A as a utility transport/training aircraft into the 1990's, accuring flight hours in excess of the currently rated fatigue life capability. Thus the need exists to identify the capability for life extension with and without structural modifications. This case study shows how an aircraft wing designed to the fatigue requirements of the late 1950's would perform to the structural integrity criteria of the 1970's as defined by military specifications MIL-STD-1530 and MIL-A-83444.

The analysis to define the modifications and inspections necessary to double the service life of the wing is described. The analysis and fatigue testing performed during the design phase is discussed. The load spectrum representing current usage of the aircraft for the life assessment as derived from load and mission parameter data collected from VGH recorders is shown. A comparison of the spectrum, representing a total of 15000 flight hours, to that used for the initial design and testing is made.

Both durability and damage tolerance analyses use the principles of linear elastic fracture mechanics with emphasis on sub-critical flaw growth. An example of the analysis demonstrates the methodology and discusses the effect of the criteria on possible structural modifications. Results of the analysis, the signigicant conclusions, and the recommendations for modification and maintenance inspections are discussed.

EVALUATION OF THE EFFECT OF SERVICE USAGE ON COMPOSITE MAIN ROTOR BLADES

Harold K. Reddick, Jr., Applied Technology Laboratory
U.S. Army Research and Technology Laboratories (AVRADCOM)
Ft. Eustis, Virginia 23604

Jack S. Hoffrichter, Boeing Vertol Company
Philadelphia, Pennsylvania 19142

ABSTRACT

The Army is currently engaged in major production procurements of composite main rotor blades for the AH-1Q and CH-47D helicopters. These blades will represent the first generation of composite blades in the Army's inventory, and for this reason there is relatively little data available on whether long-term environmental effects (ultraviolet, humidity, moisture, heat, etc.) incurred during service usage have any effect on the static, dynamic, and fatigue characteristics of composite blades. The BO-105 helicopter manufactured by Messerschmitt-Boelkow-Blohm uses all-fiberglass main rotor blades. Several of the more than 50 BO-105 helicopters currently operated in the United States have blades with accumulated service time in excess of 3,000 flight hours. To address the technical issue of long-term environmental effects on composite blades, an investigation program is underway at the Applied Technology Laboratory (ATL) of the Research and Technology Laboratories (AVRADCOM). The initial phase was contracted to the Boeing Vertol Company. This phase consisted of procuring two new and two service used BO-105 blades, defining the used blades' service history, nondestructively inspecting each blade, and statically and dynamically measuring the physical properties of each blade. The physical property tests showed no differences between new and used blades which were attributable to fiberglass deterioration. All stiffnesses and frequencies were within the same range of scatter for both new and used blades. The only differences encountered were in the magnitude of static flapwise deflection and in the damping rate experienced during the chordwise frequency test. Both of these differences were attributed to a deterioration in the potting material between the fiberglass root loop and the titanium root end fitting. For assurance that this was the cause, the root end of each used blade has been repotted and the blades are being retested for flapwise deflection and chord frequency. Testing is scheduled for completion by the end of August 1978. The nondestructive inspection by means of ultrasonic, radiographic, and coin tap revealed no internal deterioration in the fiberglass, the resin, or internal interfaces of the nonmetallic materials. Indications of surface erosion, determined by the visual inspection, were minor except at the splice joints of the titanium nose cap.

The effort currently underway at ATL includes full-scale fatigue test evaluation of the new and used blades to define any differences in their structural strength properties resulting from in-service environmental exposure. The first blade specimen is now being instrumented and should be fatigue tested by the end of September 1978. The entire fatigue test program is scheduled to be completed by mid-December 1978. Concurrent with this effort, the Army Materials and Mechanics Research Center (AMMRC) is conducting a chemical analysis of small specimens taken from each blade to define any changes in the resin system with time.

A-7E ARRESTING GEAR HOOK SHANK LIFE EXTENSION PROGRAM

David J. White
Structural Life Management
Vought Corporation
Dallas, Texas 75222

ABSTRACT

Vought is currently under a Navy contract to develop the criteria for extending the service life of the A-7 arresting gear hook shank. Fracture mechanics techniques are being used to determine the proof load required to guarantee the safe extended life of the hook shank. The program requires structural testing to provide information concerning fracture toughness, fatigue crack growth rates and critical flaw sizes for the material and geometry in question.

A-7E arresting gear are currently retired from service after 500 arrestments. This life limit is based upon the high loads encountered on carriers with Mod 1 arresting systems. Future usage of the A-7 aircraft will be on carriers with Mod 2 or Mod 3 arresting gear, resulting in lower arresting loads. Therefore, it is anticipated that (1) the safe life of hook shanks currently in service may be extended, and (2) retired hook shanks can be safely returned to service.

The Navy has initiated a program with Vought to evaluate potential life improvements by establishing proof load/inspection criteria to guarantee additional safe life of the structure. This effort is based upon using fracture mechanics techniques to establish meaningful proof test criteria. The analysis is supported by the structural testing of 30 retired hook shank assemblies. The tests provide data concerning fracture toughness of the material, critical flaw sizes, and crack growth rates.

The case study presentation will summarize the proof test theory, fracture analysis, and structural testing as well as projected life improvements based upon preliminary analysis.

CORRELATION OF A THEORETICAL ANALYSIS AND EXPERIMENTAL STRESS/BUCKLING STUDY OF A MAJOR NAVY TEST PLATFORM

Dr. R. G. Kasper
Dr. F. A. Marafioti
Naval Underwater Systems Center
New London, Connecticut 06320

ABSTRACT

A comparison study between analytical and some experimental results of a major Navy Test Platform will be presented. A number of static and dynamic force configurations were analytically imposed on the structure (via mathematical modelling) simulating expected load requirements. The load requirements were principally motivated by a need to fulfill a standard crane lift certification program prior to commencing on site operations. Due to the numerous deployment configurations of the crane boom, a number of maximum and minimum load parameters were and are presently considered.

The Navy Test Platform (800 tons) was placed through a comprehensive static and dynamic stress analysis including a check on the natural frequencies (normal mode analysis) and the suspected buckling characteristics of a significant substructure. This was further related to the dominant in situ surface wave dynamics and energy spectrums (Sea State) in order to avoid low frequency resonance problems. Elastic and plactic stress states were addressed in critical interconnecting junctions of the overall test platform. All of the various analytical efforts were performed using the NASTRAN (NAsa STructural ANalysis) Code resident on the UNIVAC 1108.

The experimental results were obtained by applying approximately 100 strain gages at critical locations on the structure with a certain amount of redundancy in key areas. The strain gage data was processed automatically through the use of signal conditioning, a digital computer, and an automatic plotter. Furthermore, this engineering effort provided an excellent means of comparing between the full-scale test and the computer math model in real time. The strain gage readings were used as an additional safeguard during the actual load lift certification program. The analysis was a significant aid in determining key stress areas thus providing an efficient and logical sensor placement guideline. Due to a number of unusual geometric/load configurations, the buckling analysis provided a significant insight since imminent buckling at approximately 60% of full lift load was diagnosed early in the analysis at the king post and boom areas.

Due to the importance of structural integrity and reliability of this measurement platform to the Navy's program, it was imperative that detailed analytical/experimental efforts were vigorously pursued. Based on the above structural investigation, a number of key structural modifications have been recommended and implemented.

DETERMINATION OF STRUCTURAL RELIABILITY USING A FLAW SIMULATION SCHEME

Joseph I. Bluhm, Donald M. Neal and Donald S. Mason
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

ABSTRACT

Reliability Calculations are made for a cannon launched guided missile structure using fracture mechanics concepts in conjunction with the Monte Carlo method. Reliability estimates are evaluated and compared for both Weibull and Warner stress strength diagram definitions.

The Weibull scale and shape parameters are obtained from a distribution of allowable stress values developed from K_{IC} (fracture toughness) relationships. The crack length and orientation in the K_{IC} function are assumed to have uniform random varations with a normal probability density function representation for the K_{IC} number. Types of cracks considered in the structure are "through" cracks, edge cracks, surface (semi-elliptical) cracks, and the corner cracks, which are all assumed remote from any significant effects of neighboring discontinuities. In the Weibull model the actual stress values are obtained deterministically from a 3-dimensional finite element code designed for static analysis of thin shells. Reliability numbers are determined for each element in the structure using the Weibull representation. These numbers are multiplied together in order to define reliability of the entire structure. The multiplication procedure introduces reliability independence between elements of the structure, thereby describing a conservative estimate.

An alternative reliability calculation method using the Warner stress-strength diagram has also been applied to each structural element. In this type calculation the actual stresses are assumed to have distribution of values in order to simulate possible errors in the finite element solution, where allowable stresses are determined from the K_{IC} relationship. Reliability (Warner diagram) is defined as the probability of the allowable stress being greater than the actual stress over a range of actual stresses in the element. Total reliability of the structure is determined in a manner similar to that described for the Weibull function.

"SHELF LIFE" OF M454 CENTER BODIES

Jacob Greenspan
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

ABSTRACT

This case study is of the "shelf life" of the M454 (8 inch shell) center body. The material is U-8Mo-1/2Ti alloy. Three components, manufactured approximately 17 years ago, and in deployment for approximately 16 years, have been retrieved, and are being examined for structural integrity. Initial specifications (1962) required tensile yield strength of 130 ksi, tensile elongation of 10%, and V-notch charpy impact strength of 4 foot pounds. Stress corrosion studies in 1962 showed a critical stress level of about 60 ksi for a 20 year life for this alloy in ambient atmosphere.

In the present investigation, ultrasonic scan, and dye check methods are being applied to detect internal or surface flaws that might have developed. Tensile, V-notch charpy, and stress corrosion evaluations are being conducted on samples removed from the bodies. Present values will be compared with those of 1962 to determine the extent of deterioration, if any.

STRESS-CORROSION-CRACKING IN A GUN BARREL DUE TO TENSILE RESIDUAL STRESS

John H. Underwood
U.S. Army Armament Research and Development Command
Benet Weapons Lab, Watervliet, New York 12189

ABSTRACT

Results are described of a current investigation to determine the cause of through-wall cracks in a 105 mm ID, 140 mm OD section of a gun barrel (muzzle of M137A1). Two cracks of about 60 and 100 mm length were observed on the OD of the barrel after firing 11,000 rounds. Since this corresponds to less than 60% of the safe life of the barrel, various tests and associated analysis were performed to determine the cause of the premature cracking.

Ultrasonic inspection in the area of the OD cracks showed several additional shallow cracks near the ID, 1 to 3 mm deep. Photomicrographs of a section through the barrel gave the best qualitative information regarding the cause of the cracking. Classic multiple-branch cracking, typical of stress-corrosion-cracking was seen along the OD cracks as well as the shallow cracks. Scanning-electron-microphotos of the fracture surface of one of the OD cracks showed intergranular brittle fracture, further confirming that stress-corrosion-cracking contributed to the premature cracking.

Two types of residual stress measurements, x-ray and slitting measurements, were performed using disks cut from the barrel near the area of cracking. The measurements show generally lower residual stresses than those expected in this autofrettaged barrel, and they show areas of tensile residual stress near the ID of the barrel, a location where compressive stress is expected.

Based on the tests thus far, the cause of the thru-wall cracks in the barrel is believed to be stress-corrosion-cracking which combined with the expected fatigue cracking due to firing. The tensile stress which is required for stress-corrosion-cracking was the residual stress, possibly resulting from the autofrettage process used; the agressive environment required for stress-corrosion-cracking was the firing products, which include H_2S, one of the most aggressive stress-corrosion-cracking environments known for steels.

TRACK PIN INDUCED STRESSES

S. B. Catalano
Army Tank-Automotive Research and Development Command
Warren, Michigan 48090

ABSTRACT

Work reported was for the period 1 October 1977 to 30 September 1978. The objective was twofold: a) To follow track pin residual stress history over the last few processing steps such as core hardening, induction hardening, straigtening, grinding and shot peening. b) To examine the data for evidence of harmful levels or patterns of residual stress that may contribute to track pin failure. A total of 100 track pins were randomly selected for this project from the last seven stages of manufacture at the manufacturer's plant. Residual stress measurements were made in both the longitudinal direction and hoop/transverse direction at 72 spots on each pin. Equipment used was automated x-ray diffraction equipment. Results of the measurements from each pin were tabulated in terms of mean and standard deviation of readings on each pin. Of particular interest to TARADCOM were: 1) Hoop stresses 30K psi less compressive than the longitudinal stresses measured at the same point were generated in the centerless grinding operation, 2) The 30K psi difference in readings is not removed in the stress relief operation, 3) It is possible to remove the 30K psi difference by shot peening.

EMBRITTLEMENT AND RUPTURE OF A LARGE PRESSURE VESSEL

Bruce W. Christ
Charles H. Brady
Fracture and Deformation Division
National Bureau of Standards
Washington, D.C. 20234

ABSTRACT

This presentation is based on work in progress at the National Bureau of Standards which is sponsored by the Materials Transportation Bureau - U.S. Department of Transportation.

This presentation describes the metallurgical and fracture analysis of a large seamless steel pressure vessel which ruptured during filling with natural gas at the wellhead. The cylindrical vessel was 34-feet long by 22-inches diameter. Reported burst pressure was about 2200 psi-design burst pressure was 6,800 psi. Tensile strength of this 0.44 carbon - 0.92 manganese steel was about 155,000 psi. The fracture originated at a part-through crack which was growing radially from the inside wall. Several smaller part-through cracks were found in the vicinity of the fracture origin. Often, they originated at tiny circumferential cracks in hard micro-zones close to the inside wall. Up to 500 ppm hydrogen sulfide was detected in samples taken from the natural gas well. It is tentatively concluded that the rupture was due to hydrogen-assisted crack formation with further crack growth being assisted by service stresses.

Results of mechanical testing and fractographic examination will be presented. A discussion will be given of a fracture mechanics assessment of critical defect size as determined from ductile and brittle fracture considerations.

WORKMANSHIP DEFECTS DETECTION

John W. Burt and Michael A. Condouris
Army ERADCOM Technical Support Activity
Fort Monmouth, New Jersey 07703

ABSTRACT

In April 1977, a study was initiated to evaluate the relative effectiveness of fixed frequency sinusoidal vibration, swept frequency sinusoidal vibration, and random vibration, for detecting workmanship defects in electronic equipments. The workmanship defects being considered in this program are only those that ordinarily would be susceptible to being damaged by vibration. After reviewing a variety of these workmanship defects, it was concluded that, for many reasons, it was impractical to include many of them in a test program. One type of workmanship defect was selected whose vibration natural frequency could be easily varied over a wide frequency range which also could be used to simulate a variety of other types of workmanship defects. A device that meets this requirement is a fastener-cantilever combination. Variations in the fastener torque and the cantilever natural frequency provided simulation of bad workmanship over a wide range of frequencies and "G" levels. The test results to-date indicate that both swept sinusoidal and random vibration are superior to the single frequency sinusoidal vibration test for detecting workmanship defects in electronic equipment.

APPLICATION OF COLLAPSE THEOREMS AND NONLINEAR FINITE ELEMENT ANALYSIS FOR THE DESIGN OF PROTECTION BARRIER OF NUCLEAR SHIPS*

P. Y. Chang
HYDRONAUTICS, Inc.
Laurel, Maryland 20854

ABSTRACT

Since the probability of collisions always exist, adequate protection for the nuclear reactor is essential for nuclear powered ships. In the past, the design and analysis of the protection barrier was based on experiments and semi-empirical methods of analysis. Existing analytical methods are not accurate because of their deviation from the proper collapse theorems.

Most designers usually assume that the structure is safe if the design load is smaller than the calculated collapse load of the structure. This is valid if and only if the method is based on the proper collapse theorem. This study describes the proper collapse theorems and the conditions which the analytical method must satisfy in order to insure the safety of the protection barrier. Errors of existing methods are also discussed.

For the safety of the nuclear ship involved in collision, the collapse load of the striking ship must be smaller than the collapse load of the protection barrier. For economical reasons the difference between these two collapse loads must be small. A mathematical model for the prediction of the collapse load of the barrier has been developed. The mathematical model for the collapse load of the striking ships will be developed next year.

*This study is sponsored by the U.S. Maritime Administration in a cooperative program with Germany.

LARGE SAMPLE STATISTICAL STUDY OF THE MECHANICAL PROPERTIES FOR FOUR GRAPHITE-EPOXY MATERIAL SYSTEMS*

Charles D. Reese
Associate Professor of Mechanical Engineering
University of Kansas
Lawrence, Kansas 66045

ABSTRACT

A large sample statistical study of four graphite-epoxy material systems are under investigation. The test program includes short beam shear, tension and compression tests. Both normal and Weibull statistical distributions are examined for best fits of the data. Special consideration is given to the fit in the tail regions of the failure distributions and the resulting impact on design reliability. The tensile and short beam shear test results are to be reported in this case study.

This investigation provides statistical data in support of NASA Langley's ongoing study of the long-term ground and flight environment exposure on the behavior of graphite-epoxy spoilers. The materials under test were fabricated for NASA Langley by Boeing Seattle using the same fabrication procedures utilized in the manufacture of the graphite-epoxy spoilers for the environmental flight test program. Three of the material systems tested are Union Carbide Thornel 300/2544, Narmco 5209/300 and Hercules 3501/A-S. The fourth material system is a control group that was fabricated along with 25 additional spoilers that were prepared for static and environmental tests by NASA Langley. These spoilers and their control test materials were fabricated by Boeing using the Narmco 5209/300 material system. The tests in this investigation provide an opportunity to examine the failure statistical distributions for large samples of three similar graphite-epoxy material systems. The two Narmco material groups were manufactured at different times and provide an opportunity to examine the repeatability of material properties and manufacturing method for this type of composite system. Repeatability and predictability of material properties and characteristics is essential to the design process. This study provides a large sample comparison of the repeatability of one graphite-epoxy system.

The statistical data obtained thus far indicates that while both normal and Weibull projections provide a reasonable fit throughout the midrange of the distribution, the lower tail region (design region) is best represented by the Weibull criteria.

*This work performed under NASA Langley Grant NSG 1281

AUTHOR INDEX